Models and Approaches to STEM Professional Development

Brenda S. Wojnowski and
Celestine H. Pea, Editors

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FOREWORD

Patricia M. Shane

This volume arrives at a most propitious time for those involved in science education in the United States. As a nation, we are entering a time of significant transition as we prepare to digest, assimilate, and enact the changes inherent in achieving the goals of the *Next Generation Science Standards* (*NGSS*). These changes allow for a focus on the core ideas in science and engineering as well as their practices and the crosscutting concepts that are common to both dimensions. Integral to the process of change is the need to be removed from the comfort zone of our current practices. Thus, no matter how great the recognition of the need for change, the process remains arduous and stressful—even for the most passionate proponents.

Models and Approaches to STEM Professional Development provides direction to managing the changes entailed in adoption of the new standards. It takes a meaningful look at the history of professional development in science education, discusses challenges of the new standards and related research on learning, highlights critical aspects of successful programs, and provides forward-facing insights into the needed professional development surrounding the *NGSS*.

The case for the importance of science, technology, engineering, and mathematics (STEM) reforms and their relevance to professional development is clearly delineated by the authors. Considerable attention is given to creating new ways of listening to and monitoring students' scientific reasoning and thinking as well as the importance of professional development designed to enact science reforms. Concomitantly, careful blending of what is new, especially *A Framework for K–12 Science Education* and the *NGSS*, with the successes of existing science professional development programs are strengths of this volume. As George Santayana so eloquently said, "Those who cannot remember the past are condemned to repeat it." Because the advent of new standards doesn't mean ignoring successes of the past, wise implementers will embrace those programs that have been successful and build upon them as they embark on new endeavors.

Because it emphasizes the strengths of existing models, this book does an excellent job of sharing the advantages of nine successful science professional development programs across the country. Some are local programs while others are statewide or regional, but they have elements in common such as grassroots efforts, involvement of the players in developing a program, in-depth professional development over time, and formative evaluation to guide ongoing program revision. Further, insights into the sustainability of the programs are detailed. These are all programmatic elements that need to be considered as we embark on the next stage of science education reform in the United States.

Leaders from across the country have come together in this volume to share their cumulative wisdom about lessons learned. The book demonstrates how new wheels do not have to be invented to enact the *NGSS* and clearly lays out considerations and methodologies for building on current science education wheels while incorporating new research about how students learn. These themes are deftly developed and articulate the appropriate pathways to achieving the goals of the new science standards. The lessons learned from successful programs are provided along with specific examples of what made them thrive. In addition, considerable attention is given to developing new ways of listening to and monitoring students' scientific reasoning and thinking. In sum, this volume combines the best of what we have learned since the advent of science reform in order to prepare us for the transition to the recently released *NGSS*.

ABOUT THE EDITORS

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Brenda Shumate Wojnowski, EdD, is president of a Dallas-based education consulting firm geared toward nonprofit and university clients. She is a past president of the National Science Education Leadership Association (NSELA) and a past chair of the National Science Teachers Association (NSTA) Alliance of Affiliates. Dr. Wojnowski edits the NSELA journal, *Science Educator*, and chaired the 2010 NSTA STEM (science, technology, engineering, and mathematics) task force. She has been engaged in university- and foundation-based programs for over 25 years, with prior experience in public schools. During her career, she has served as senior program officer for a nonprofit foundation and president of a museum-based nonprofit. Dr. Wojnowski has held a variety of university positions, including teaching graduate-level courses in educational leadership and researching and supporting STEM areas. An award-winning K–12 teacher, she has taught at the middle and secondary levels and has served as a high school curriculum administrator. She holds a doctorate in curriculum and teaching with postdoctoral work in educational administration, a master of arts in middle grades education, an undergraduate degree in biology with a minor in secondary education, and teaching and supervision licensures in eight areas. She has presented numerous workshops and invited talks as well as having served in a senior level capacity on many grants and contracts from public agencies and private foundations. Dr. Wojnowski has numerous publications to her credit. Her research interests are in STEM areas, school reform, and the mentoring of beginning teachers.

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Any opinions, findings, conclusions or recommendations expressed in this chapter are those of the authors and do not necessarily reflect the views of the National Science Foundation in any way.

Chapter 3

The Importance of Viable Models in the Construction of Professional Development

Joseph Krajcik

We live in an exciting time in science and science education. Over the last 10 years, many amazing new scientific breakthroughs have occurred that impact our daily lives: genomics, nanoscience, and the use of digital technologies for communications, to name just a few. These breakthroughs give us more control over serious illnesses and allow us to communicate globally through pictures, voice, and text in real time using handheld technologies and to travel the globe within a day. While amazing and useful, these scientific breakthroughs give rise to many technical, ethical, and moral problems such as global warming, pollution of waterways and the air, decrease and loss of species, and a dwindling supply of energy and other resources. Hence, the children of today will grow up in a world in which they will need to apply scientific concepts, communicate ideas, make sound decisions based on evidence, and collaborate with others to solve these problems and prevent them from escalating.

In the past 15 years, learning and cognitive scientists have made tremendous advances in our understanding about how students learn science and how science should be taught to help prepare students for the rapidly changing world. These ideas have been well documented in several publications by the National Research Council (NRC), such as *How Students Learn: History, Mathematics, and Science in the Classroom* (Bransford and Donovan 2005), *Knowing What Students Know* (Pelligrino, Chudowsky, and Glaser 2001), *Taking Science to School* (Duschl, Schweingruber, and Shouse 2007), *Ready, Set, Science!* (Michaels, Shouse, and Schweingruber 2008), *America's Lab Report* (Singer, Hilton, and Schweingruber 2005), *Successful K–12 STEM Education: Identifying Effective Approaches in Science Technology, Engineering, and Mathematics* (NRC 2011) and *A Framework for K–12 Science Education* (*Framework*; NRC 2012). The findings reported in these publications clearly show that to be productive 21st-century global citizens, learners need to develop integrated understanding of big ideas of science by applying and using big ideas to explain phenomena and solve problems important to them. By "integrated understanding" I mean that ideas are linked together in a weblike fashion that allows learners to access information for problem solving and decision making (Fortus and Krajcik 2011).

The *Framework* provides a coherent picture of the major scientific and engineering ideas and practices that all learners need to understand in order to live productive lives as citizens in this century and, if desired, to pursue further study of science and engineering. The *Framework* makes use of four key ideas: (1) a limited number of big ideas of science, (2) an ongoing developmental process, (3) the integration or coupling of core ideas and scientific practices, and (4) crosscutting elements.

The *Framework* laid the foundation for the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013), in which we find the blending of core ideas with scientific practices and crosscutting concepts that is central to the *NGSS*. With these breakthroughs in science education, the implications are clear for what inservice and preservice teachers must do to be prepared to teach new scientific ideas using sound pedagogical methods to support students. Taken collectively, the country needs to develop and institute a nationwide approach aimed at preparing top-notch K–12 science teachers before they enter the teaching profession and an equally effective program for providing high-quality professional development to practicing teachers, regardless of the route taken.

How can we use the *Framework* and the *NGSS* to inform teaching and learning and its concomitant professional development? These publications will likely serve as the core that education stakeholders at all levels will rally around to establish such an educational infrastructure. The documents clearly demonstrate that what we teach needs to change because of what we know. Rather than focusing on multiple ideas, the *Framework* recommends that teachers help students develop understanding of the core ideas of science because these will help learners form a foundation for lifelong learning.

As an example of this process and its implications, one of the core ideas in physical science in the *Framework* is Energy, and one of the crosscutting concepts is Energy and Matter. All teachers from kindergarten through high school will need to present a coherent vision of energy. Previously, the concept of energy was relegated to physical science courses. As such, students had a hard time seeing the similarities of the energy discussed in chemistry and biology with the transformation of kinetic energy to gravitational energy in physics class. Within our own teaching, we create a schism, whereas, energy is in reality a crosscutting concept essential to all of the disciplines. As the *Framework* stresses, the idea of energy is essential in examining the systems of life science, Earth and space science, chemical systems, and engineering contexts. The idea of energy needs to be taught not just in physics or physical science, but across the grade levels and integrated into all of the science, technology, engineering, and mathematics (STEM) subjects.

Energy is difficult to define, yet we can track energy as it transfers across various systems. Since many teachers have never been taught to teach energy in this powerful way, this approach will need to be embedded into professional development at all levels. Elementary teachers will need to be able to introduce the idea of energy in ways that middle and high school science teachers can build on to further help students develop deeper and more powerful ideas of energy that can be used to explain phenomena and solve problems.

What model of professional development can we use that will help teachers at the elementary level develop an understanding of energy while also providing the tools to support elementary students beginning to form an understanding of energy? How do we support middle school teachers in developing a deep and integrated understanding of energy across the grades and the various disciplines and to link the ideas together within and across the grade levels?

With respect to how we teach science, many classrooms in the United States still resemble classrooms of the early1900s, with outdated equipment and pedagogical strategies that fail to promote learning for most students. John Dewey bemoaned, in 1910, that education focuses too much on facts and not on how knowledge is generated. We heard a similar cry from Schwab in the 1960s and again from Bruce Alberts in 2009. Although we have seen some changes, learning science is still too much like learning a language and not enough about explaining how the world works. Teaching in which ideas build upon each other is in many ways a foreign idea to science teachers. Although it is a hallmark of teaching and learning because it ties to the importance of connecting to prior knowledge, linking conceptual ideas across time is a challenging pedagogical practice that is seldom observed in the teaching of science. Yet, it can have a powerful influence on student learning (Roseman, Linn, and Koppal 2008).

Today we know much about how to engage students in constructing, revising, and communicating models and in building and communicating explanations from evidence. Students need to engage in model construction and revision as well as in the building and communication of explanations based on new evidence in order to explain phenomena (NRC 2011; Krajcik and Merritt 2012; McNeill and Krajcik 2011). For the science education community, beyond providing a newer student-centered approach to professional development, another major challenge lies in our nation's large urban cities and rural areas in which classrooms are increasingly filled with underrepresented populations from a variety of cultures (e.g., Hispanics, African Americans, Asians). As a nation, we face the tremendous challenge of how to provide quality science education to diverse learners whose culture and ways of knowing may vary significantly from those of their teachers, necessitating professional development that includes ways to address the cultural and linguistic issues inherent to such classrooms (Moje et al. 2001). The question then becomes how do we support teachers in learning and enacting these important scientific practices?

The Problem

Although the *Framework* and the *NGSS* are critical steps in upgrading science education in the United States, their impact will be limited by the degree to which K–12 teachers implement the *NGSS* with fidelity. Unfortunately, past experience with adapting standards suggests that implementing the *NGSS* as intended by their developers may be compromised because of the ways local school districts interpret the standards (Spillane and Callahan 2002). For example, we can expect the terms "learning progressions" and "scientific practices" may take on a wide range of meanings as they are introduced to teachers and school personnel. Many of these interpretations will diverge from the *Framework* committee's intentions. Teachers also have a tendency to judge their activities as aligned to standards even when "diverging widely" from that which was intended (Penuel et al. 2009, p. 28). For instance, many teachers felt they were doing inquiry in the classroom when students did a hands-on activity, but hands-on does not necessarily equate to doing inquiry. Moreover, the *Framework* and the *NGSS* will not be sufficient resources for helping teachers learn about and enact the standards. Teachers will need professional development in how to interpret and implement the next generation of standards in their teaching, and until new teaching materials are developed, teachers will need to know how to blend the ideas in the *NGSS* with their current learning materials.

How do we prepare teachers of science, particularly those who graduated in the past, with new scientific ideas and new understandings of how to teach? Unfortunately, many science teachers in our schools have not continued in their professional growth. There are many reasons for teachers not taking part in professional development in our country, including lack of national and state policies that provide both financial backing and time for this commitment. Yet, taking part in professional growth opportunities to learn new science ideas and new methods on how to teach children is critical. The infrastructure for professional development in science education has changed significantly since the first generation of science standards. Given the limited time available for face-to-face professional development and the increasing budget constraints for carrying out professional development, what viable models can be used to support teachers in enacting *and understanding* essential features of the next generation of science standards? What innovative curriculum and new teaching ideas have emerged in the field? How do we support teachers in developing the pedagogical content knowledge they need to help learners? As a nation, we need to build cost-effective, scalable, accessible professional development models that can support teachers in understanding innovations such as the vision painted in the *Framework* and the *NGSS*.

How important is professional development? Forty years ago, when I was in my late teens and early twenties, I was a good car mechanic. I felt competent to open the hood or crawl under most cars to fix them. I even put a new clutch (not a simple procedure) into my Volkswagen bug. But today, I can't even find the batteries in most cars. Although cars today look superficially like they did in 1970 and still mostly run on internal combustion engines, the internal workings of most new cars are based on updated computer technologies. I never kept up my education as a car mechanic, and with changes in the design and running of cars, my knowledge is old and outdated. Although I could probably still change the spark plugs in a 1968 Volkswagen bug, that knowledge is no longer useful for today's cars. Today I would have no clue about what to do if my car stalled except to make a phone call. The same thing is true of teaching. Just as you would not want me working on your 2012 Volkswagon because I no longer have that knowledge or skill, many teachers do not have the knowledge and teaching skills for teaching in today's classrooms. They did not keep up with their professional development. What we teach and how we teach has changed. While classrooms superficially look the same, what we do in them needs to be very different.

The NRC in *Taking Science to School: Learning and Teaching Science in Grades K–8* (Duschl, Schweingruber, and Shouse 2007) argues that well-designed professional development opportunities for teachers can produce the desired changes in classroom practices and contribute to improvements in student learning. But to do so we need viable models of professional development that we know work. Kubitskey and Fishman (2007) support the statement made by the NRC and propose a model of how professional development can influence student outcomes. They believe professional development activities can influence teacher buy-in to an innovation and to the teacher knowledge and confidence needed for the innovation to occur. These components are critical to the practices that teachers use in the classroom and that, in turn, will influence student learning. What is also critical is that we learn more about what type of professional development activities are most promising.

Unfortunately, although we have gained knowledge of what can work, the field lacks knowledge in how to scale and support the use of these new ideas. Typically, professional development institutes do not allow time to provide teachers with the background necessary to teach new ideas. Often ideas are presented superficially and the rationale behind the idea and the importance of using the ideas with fidelity is not stressed. Too often, professional development focuses on presenting the innovations to teachers without engaging them in the process. As such, many science teachers often adapt their use of innovation based on their prior knowledge of teaching and learning, which causes the new methods to resemble traditional classroom practices.

Building Professional Development Models From What Is Known

Professional development that supports teachers' learning has been shown to be a key factor in improving the quality of schools (e.g., Borko and Putnam 1995) and student learning (Desimone et al. 2005; Heller et al. 2012). Previous research indicates that professional development for science teachers needs to have several key features, including clearly specified learning goals that focus on instruction and student outcomes and highly interactive sessions that engage teachers in a community that supports their learning (Darling-Hammond 1997). Professional development must also provide opportunities for collective meaning making and focus on authentic problems from the teachers' perspective. Moreover, we know professional development needs to be sustained over a long period. Such professional development can lead to desired changes in teacher knowledge and practice (Penuel et al. 2007).

Lee and Krajcik (2012) suggest a viable model to develop teacher knowledge and teaching skills through a combination of effective professional development and educative materials embedded in the curriculum (Davis and Krajcik 2005; Remillard 2005). Educative materials build supports into teaching materials that allow teachers to enact the innovation as intended.

Yet, what goes into these professional development models? What features of professional development should be focused on? Moreover, we need evidence to support these models.

A Model Supported by Research

Here I discuss a viable model of professional development that stems from the work of Joan Heller and colleagues (Heller et al. 2012). Heller and colleagues used a randomized experimental design, implemented in six states with over 270 elementary teachers and 7,000 students in order to compare three related but systematically varied teacher professional development interventions (*Teaching Cases*, *Looking at Student Work*, and *Metacognitive Analysis*) along with a no-treatment control group. The three interventions contained similar science content components but differed in the ways they incorporated analysis of learner thinking and of teaching. Another critical aspect of their design involved facilitators not involved in the design of the interventions to deliver the professional development sessions. This design made it possible to measure effects of the unique feature of each intervention on teacher and student outcomes. The findings indicate that each intervention improved teachers' and students' scores on selected-response science tests significantly and substantially beyond those of control students, and the effects lasted until a year later. Student achievement also improved significantly for English language learners in both the study year and follow-up, with the intervention effects not differing based on sex, race, or ethnicity. However, the research team did see important differences resulting from the various interventions. Only the *Teaching Cases* and *Looking at Student Work* interventions improved the accuracy and completeness of students' written justifications of test answers on follow-up assessments, and only *Teaching Cases* had sustained effects on teachers' written justifications. Although the content component that was common across the three interventions showed powerful effects on teachers' and students' ability to select correct test answers, the ability to explain why answers were correct only improved when the professional development incorporated analysis of student conceptual understandings and implications for instruction.

These findings are important for several reasons: First, they show that professional development that integrates content learning with analysis of student learning and implications for instruction can impact student learning. Second, the study demonstrated that high-quality professional development of moderate duration can be delivered by facilitators not involved in the development of the interventions and can have considerable and lasting impact on the teaching and learning of elementary science. In addition to the impact, points one and two are important because they illustrate that other professional development models need to incorporate and test these components. Third, the effects of the interventions were stronger for teachers' students in the follow-up year, suggesting that teachers need to have several iterations before students in their classrooms experience the full impact of the professional development. Often in measuring professional development, we take one-shot approaches that don't allow teachers opportunities to develop their understanding further, and we do not measure impact across years. Fourth, only a few studies have shown a causal link between the professional development intervention and student outcomes. The study by Heller and colleagues provides an excellent example for others in the field to replicate at different grade levels and for different content. As such, their model provides an excellent example of an effectiveness study in the cycle of development and research.

A Professional Development Model to Support Enactment of Innovative Curriculum

Using learning goals–driven design (Krajcik, McNeill, and Resier 2008), we developed a middle school science curriculum for grades 6–8 with curriculum coherence as a central design principle (Shwartz et al. 2008). *Investigating and Questioning Our World Through Science and Technology* (IQWST; Krajcik et al. 2011) is a project-based curriculum comprising biology, chemistry, physics, and Earth science units that focuses on building big ideas across time, using scientific practices and engaging students in explaining phenomena. Because IQWST stresses the development of big ideas blended with scientific practices across time, it matches closely the ideas in the *Framework*. This brings challenges not only in introducing teachers to a new curriculum but also to engaging teachers in learning core ideas blended with scientific practices. How do you design a weeklong professional development institute to support teachers in enacting a yearlong, project-based curriculum in which ideas build on each other?

Our model focused on engaging teachers in pedagogy and practices common to all units during a one-week summer institute in order to provide teachers with generalizable knowledge for teaching a full year of IQWST (Krajcik et al. 2008). We learned early on that it is important to collaborate with teachers in designing professional development experiences and to engage teachers in the doing of science during these experiences (Krajcik et al. 1994). The summer institute was followed by a two-day, unit-specific professional development preceding the teaching of each new IQWST unit to reinforce the generalizable ideas in the new context. A key aspect of our work involved teachers in experiencing the materials through model teaching and reflection.

The generalizable knowledge we intended teachers to come away with included

- contextualizing learning using a driving question and a driving question board to frame each unit, and providing a series of investigable questions that motivate students with a need to know;
- scaffolding specific scientific practices such as creating and testing scientific models and constructing scientific explanations as important approaches to classroom inquiry;
- reinforcing classroom learning by providing students with age-appropriate, expository text written to support a range of learners as they read about science in and out of the classroom and engage in multiple ways of expressing their understanding;

- focusing on helping students develop a deep understanding of each unit's learning goals through a coherent instructional sequence and showing teachers how to link ideas within units using the driving questions and driving question boards; and
- fostering a collaborative classroom culture by focusing on specific types of interactive classroom discussions.

Assessment of teacher artifacts created during the workshop indicated that teachers recognized and appropriately described key features of IQWST and that they began to realize the challenges of implementing the materials in their own classrooms. The artifacts also revealed that the teachers constructed evidence-based scientific models by experiencing phenomena and engaging in lessons on how to construct evidenced-based models. Analysis of workshop records further indicated that teachers engaged in alternate classroom discourse patterns described by the facilitators and used in IQWST materials. Teachers were also able to identify key IQWST features, explain their importance, and describe their associated challenges in enactment. During the workshop, teachers discussed challenges to implementing IQWST, such as facilitating discussions, differentiating instruction, and engaging students to develop evidence-based classroom models over a series of lessons.

The findings from this study suggest that, given the limited time teachers are able to dedicate to professional development experiences, focusing on generalizable pedagogical components of reform-based materials—those that are not specific to units but that apply across units and could be used in other situations as they are tied to what is known about student learning—may be an important way to shape teacher practice. Our work also illustrates that engaging teachers through modeling teaching and engaging with materials is essential to learning. However, this research is at the design, develop, and test phase of the cycle. Although we have some evidence that focusing on generalizable principles can support teachers, we need to take this research to the next phase of the cycle.

Uses of Technology

Given the current state of limited time and resources juxtaposed against the number of teachers that need professional development, technological advances in using synchronous and nonsynchronous communication become invaluable in improving the knowledge and skills of teaching. One of the greatest advantages of using a technological delivery method is that one can impact a large number of teachers at any given time. With the cost of tablet computers lowering to affordable price levels and connectivity speeds increasing, high-quality professional development could be delivered on an as-needed basis through interactive online sources. Under this condition, educators can watch videos of experienced teachers enacting lessons, see how to perform investigations, watch how to support student-to-student dialogue, and learn about challenges students face in learning the ideas. Although online interactive materials are expensive to develop, many institutions of higher education, educational nonprofit organizations, and educational technological-based firms are actively meeting the challenge. It is only through multiple avenues for meeting the demands for effective professional development that we will see results in subsequent classroom practices and student achievement.

A New Professional Development Model Under Study

To support teachers in enacting the *NGSS*, my colleagues and I are developing, testing, and revising a model for professional development for the *Framework* and the *NGSS* on the basis of what we know about effective professional development. The iterative professional development model is intended to support teachers in

- developing understanding of what is meant by core ideas, scientific practices, and crosscutting concepts.
- developing understanding of how to blend core ideas with scientific practices and crosscutting concepts to develop learning performances or learning goals. This is the same process that will be used to create the next generation of standards.
- modifying existing instructional materials by identifying core ideas, scientific practices, and crosscutting concepts.
- developing learning tasks and assessment measures that will meet learning performances or learning goals.

Although we have implemented this model once with some degree of effectiveness, on the basis of responses from teachers, we know we are only at the beginning stages of our logic model for research and development.

Concluding Comment

With the release of the *Framework* and the *NGGS*, we have the opportunity to improve the teaching and learning of science and to help move our nation forward by providing all students with the depth of understanding of big ideas, scientific and engineering practices, and crosscutting elements needed to be productive citizens and leaders in the 21st century. However, extensive professional development based on viable models supported by careful research is needed in order for teachers to implement the vision outlined in the *Framework* and the *NGSS* with fidelity in science classrooms.

Several features of such professional development discussed in this chapter include

- engaging teachers in analyzing student work,
- engaging teachers in learning generalizable features of new curriculum materials, and
- building teachers' understanding over time.

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Models AND Approaches TO STEM Professional Development

"This book highlights professional development models and approaches used by several states and districts to significantly improve teaching and learning in one or more areas of STEM education, with significant emphasis on science and, to a lesser degree, mathematics education. The overarching goal for each model or approach included in the book is to develop teachers' and students' knowledge and skills, and, ultimately, to improve student achievement in STEM education."

—The editors of *Models and Approaches to STEM Professional Development*

The arrival of the *Next Generation Science Standards* (*NGSS*) makes this a great time to kick-start your professional development program for training proficient teachers—and this ambitious book is the perfect source of inspiration to help you do so.

As the editors say, the book's emphasis is on creating highly effective teachers capable of improving student achievement in STEM education; its focus is on large-scale, long-term, research-based models that underlie reform efforts in cities, districts, and states across the nation. The book opens with expert views on the history of professional development in science education, the challenges of the new standards, and related research on learning. Then, the book's core highlights critical aspects of several successful programs and provides forward-looking insights into STEM-based professional development.

Models and Approaches is a vital resource for state, district, and school leaders as well as classroom teachers. It will help you to both analyze what you do now and implement fresh strategies for making your STEM professional development more effective at all levels.

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